

UNMUDDLING THE MUDLOBSTER; OBSERVATIONS ON THE AGE AND TAPHONOMY OF FOSSIL *THALASSINA*

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ABSTRACT

The natural history of the mudlobster *Thalassina anomala* (Herbst) explains the abundance of fossils of these creatures. After each moult, the cast off exoskeleton remains in the burrow where it undergoes rapid carbonate permineralization. The condition of the fossil exoskeletons give direct evidence of the moulting process of *Thalassina* Latreille. A general account of living mud lobster natural history is given and an estimate of the age of local *Thalassina* fossils is made.

KEYWORDS: *Thalassina anomala*, mudlobsters, burrows, exuviae, fossilization, Recent age.

INTRODUCTION

Attractive crustacean fossils known locally as "scorpions" or by other misnomers have been popular items with amateur collectors in northern Australia for many years. Specimens of fossil mudlobsters (*Thalassina* sp.) are available as souvenir items from several commercial outlets in Darwin. Recently improved access to one of the best known localities of fossil *Thalassina* sp. has meant attractive examples for amateur collections, display and commercial purposes can be found in reasonable abundance (Figs 1,2). Several members of the curatorial staff of the N.T. Museum have experienced an increase in public requests for information on specimens they have found or purchased. Public enquiries usually concern identification, age, commercial value and legality of export. We have also been casually monitoring the possible depletion of the resource and destruction of source areas by digging or increased vehicle access. It has come to our attention that bulk shipments of these fossils have been apprehended by customs officials before they could be shipped overseas. While we have no indication of the market value of *Thalassina* sp. fossils in overseas markets, we can assume, from the extent of price ranges within Australia (\$1.50-\$50.00) that it will be inflated and that misinformation or lack of information about the fossils will accompany the sales. In 1984 a Darwin newspaper and a local radio interview program innocently contributed to the bulk of misinformation about the fossil mudlobsters through interviews with a French "Palaeontologist" who

vented his spleen on the complacency of local scientists with regard to the study of the *Thalassina* Latreille fossils, which he considered to be millions of years old.

In fact, there is an adequate though scattered and somewhat obscure literature on living and fossil mudlobsters that would give any interested person a reasonable account of them, beginning with Professor Thomas Bell's paper in the *Proceedings of the Geological Society* for 1884. Etheridge (1916) summarizes the literature on *Thalassina* from Australia up to the time of publication. Subsequent popular notes have appeared among which Bennett (1968) stands out as the most useful.

This paper provides information on the natural history of living *Thalassina* species including information we consider relevant to the interpretation of the fossil material that clarifies many poorly understood aspects of their palaeontology. An account of their distribution as living and fossil forms and how anatomical structure and habits relate to their appearance and mode of occurrence as fossils is provided, as is an estimation of their geological age.

THALASSINA NATURAL HISTORY

Mudlobsters are shy, secretive creatures rarely seen by even the keenest observer. Inhabiting burrows up to two metres in depth and seldom venturing to the surface, much of the life and habits of these animals is mysterious. Records of mudlobsters (see Rollet 1981 for bibliography) indicate the animals are always associated with mangrove habitats,



Fig. 1. Distribution of *Thalassina anomala*.

either living within mangroves or immediately adjacent to them. This association is because both mudlobsters and mangrove trees require muddy substrates. The genus *Thalassina* has a tropical Indo-West Pacific distribution (MacNae 1968) in common with a large component of the fauna of mangroves in our region (Fig. 1). Several species or varieties have been identified, though at present the taxonomy of the genus is in a state of flux. Although all Australian material has been referred to *T. squamifera* De Man by Poore and Griffin (1979), we propose to include all local living and fossil *Thalassina* species under *T. anomala* (Hrbst) pending a revision of the genus.

In Australia *T. anomala* occurs from Exmouth on the north-west coast (Jones, pers. comm.), northwards along the tropical coastline whenever suitable conditions occur, down to Gladstone on the north-east coast (Gillies 1951; MacNae 1966). Cooler temperatures exclude the majority of mangrove tree species from subtropical and temperate latitudes and is possibly also the limiting factor in the explanation of the distribution of *T. anomala*.

Within a mangrove mudlobsters occur from the seaward edge up to a level that depends on the physical characteristics of the site. In the monsoonal tropics where coastal environments experience a protracted dry season mudlobsters do not occur at the upper levels of the intertidal zone. At these high

levels on the shore it is likely an animal susceptible to dehydration like *T. anomala* (Sankolli 1963) is restricted in distribution by the increasing depth to which it has to burrow to enter the water table. In the everwet regions of the tropics, this restriction does not apply and mudlobsters can be found in the brackish water swamps of the upper intertidal zone (MacNae 1968) where its digging activities can produce large islands of mud.

The first overt sign of mudlobsters in a mangrove are the large piles of mud the animals have excavated from their extensive network of burrows. The burrow is a complicated structure, full of interconnections and blind endings. The burrowing activities of mudlobsters have several important ecological ramifications.

A proportion of the water-borne nutrients entering mangrove ecosystems eventually diffuse through the aerated surface layers of the muddy substrate to a depth beyond the reach of the root systems of mangrove trees. The copious amounts of mud from depths up to two metres brought to the surface by *T. anomala* returns nutrients to the surface layers from which they are absorbed by the nutritive roots of mangrove trees. Another benefit of mudlobster and other burrowing fauna excavations is the increased depth of aerated soil in mangrove habitats.

The abundance of *T. anomala* occurring in a typical muddy location has never been accurately assessed — hardly surprising con-

sidering if it were not for the distinctive piles of mud ejected from their burrows we would have little idea of their presence at all. However, we believe a reasonable estimate of density can be derived from a walk through a mangrove after the tide has just uncovered the seaward fringe. At this time many of the resident mud lobsters are in the process of ejecting mud from their burrows. The much darker coloured freshly deposited mud is easily recognized signifying a mudlobster in occupancy of the burrow. On this basis, several of the seaward fringes of mangroves in the Darwin region would support something in the order of 3-4 individuals per 10 square metres. At higher levels of the intertidal zone the mounds of mud above each burrow are much larger as there is less erosion by tidal currents. There are fewer burrows at these higher levels.

Populations of *T. anomala* can be large enough to support commercial exploitation. In Fiji, an ingenious method of trapping mudlobsters (Pillai 1985) supplies 19 per cent of the crustaceans available for sale in local

markets, even though the animals are only caught for six months of the year.

Interviews with local indigenes in northern Australia have established that mud-lobsters are a component of the diet of coastal aborigines. The importance of this resource or the method of collection is not known.

There is some disagreement among authors as to what mudlobsters eat. Pearse (1911) reported the presence of vegetable matter in the gut of a specimen he examined and concluded the animal had been feeding on the stems of vascular plants. After the examination of a dozen specimens of mud lobsters from mangroves in Malaya, Johnson (1961) proposed the animals are mud feeders, ingesting mud while in the burrow and digesting the algae, protozoa and detritus adhering to each particle of mud. He found the mouthparts and gut exhibited features consistent with mud feeding. It is possible, however, that mudlobsters eat the softer root tissues of mangrove trees, something that could be accomplished in the burrow and would not require mouthparts adapted for



Fig. 2. Location of fossil *Thalassina* sites in northern Australia. From left to right: King River, Daly River, Gunn Point-Darwin, South Alligator River.

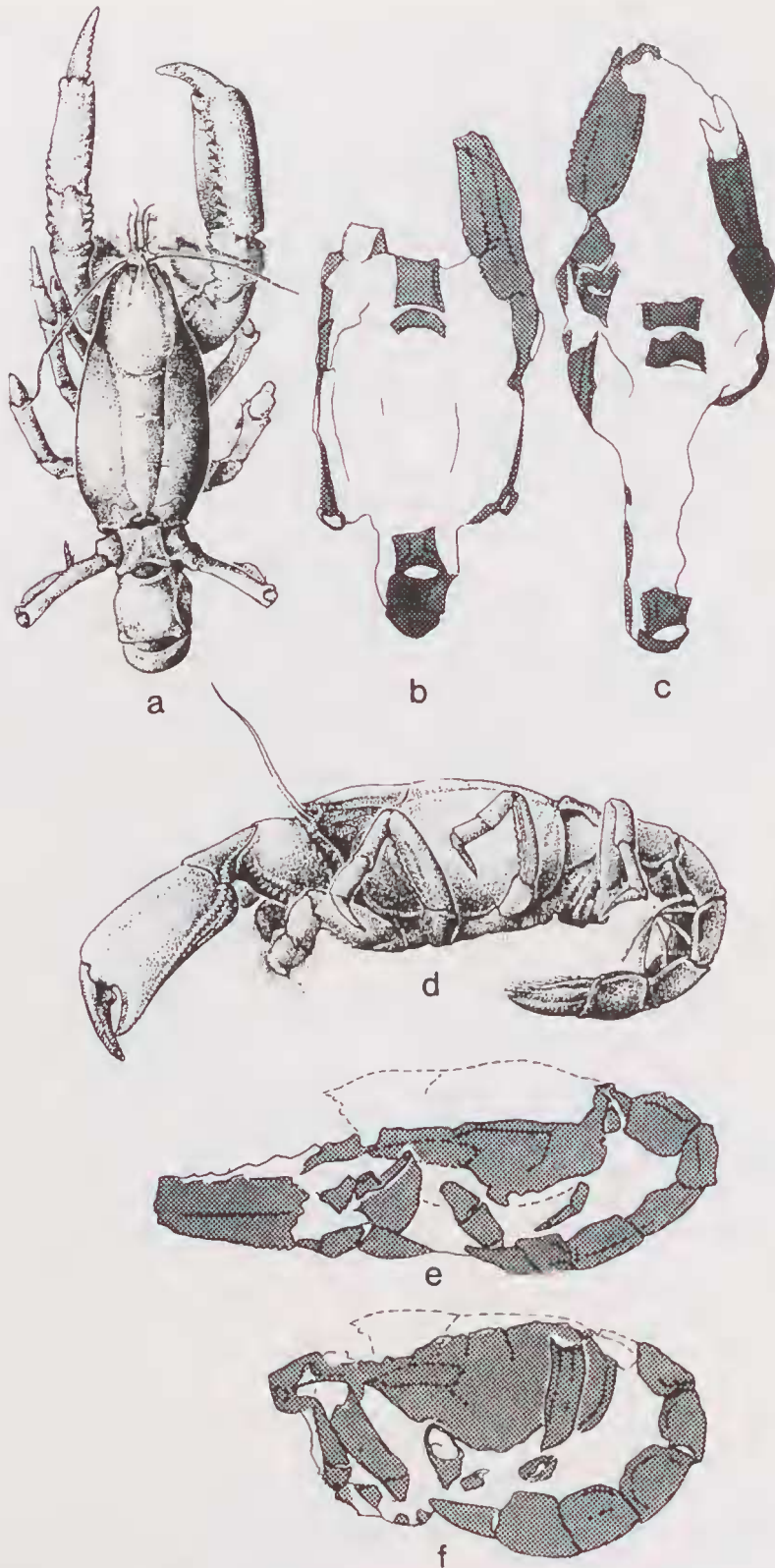


Fig. 3. Comparison between preserved and fossil *Thalassina* material: a-c, dorsal view; d-f lateral view.

eating hard vegetation. Therefore, the question of diet must await further investigation.

We know even less about mudlobster reproductive behaviour and can only assume mating occurs in the burrow. Pillai (1985) records that at Laucala, Rewa, in the Fijian islands, the spawning peak of mudlobsters is between September and November, with berried females carrying up to 100,000 eggs on the pleopods. It is thought that the female mudlobsters come to the surface during nocturnal high tides to disperse the pelagic zoea larvae. The larvae spend some two to three weeks in the plankton before migrating to brackish water for the latter stages of larval life.

THALASSINA MORPHOLOGY

Detailed descriptions of *Thalassina* species for systematic or functional anatomical purposes should be sought elsewhere (De Man 1928). Adult *T. anomala* range between 150 mm and 250 mm in length from the tip of the rostrum to the end of the telson. Female fossil *Thalassina* specimens can be distinguished from the males by their broader, deeper tergites (abdominal plates) and deeper more flared abdominal pleurites (ventro-lateral extensions of the terga) (Fig. 3). The main body parts consist of a large cephalothorax and a long, narrow abdomen composed of 6 dorsal segments and a telson. Typical of anomuran decapods, *Thalassina* has five pairs of legs. The first of these, the chelipeds, are equipped with large claws. The second pair of legs are smaller versions of the first chelipeds. The remaining three pairs are walking legs, of which the last pair (5th) are weak and spindly. Each walking leg terminates in a pointed dactyl. *Thalassina* specimens often have one first cheliped that is much larger than the other. In forms where this is a consistent dimorphic feature it is called the major cheliped. This feature is inconsistent and variable in the fossil *Thalassina* sample from the Darwin area.

In fossil specimens details of the oral and sensory region underlying the rostral projection of the anterior carapace ("head") are usually damaged or obscured. Living *Thalassina* have a pair of diminutive eyes on short stalks laterally protected by an orbital spine that projects from each side of the rostrum. Paired antennae arise ventrolaterally from below the ocular peduncles. The smaller

antennules arise from paired bases situated medially to the antennae. The antennae and antennule bases bear an arrangement of spines that are species diagnostic for *Thalassina*. These structures have not been examined in detail on the fossil specimens for the reasons already mentioned.

The carapace structure of *Thalassina* is of importance for understanding the presentation of *Thalassina* fossils (Fig. 3). The large paired lateral portions of the cephalothorax (branchiostegites) are usually well preserved in the fossils. The mid-posterodorsal portion of the carapace however, is invariably missing in fossil specimens resulting in a wide gap between the branchiostegites. The anterior carapace is attached to the posterior or gastro-cardiac portion by a deep crease called the cervical groove. Another pair of grooves called the *lineae thalassinica* delineate the attachment of the sides of the posterior carapace with the branchiostegites. These and other relevant structures are shown in Fig. 3.

PRESENTATION AND MODE OF OCCURRENCE

Fossil *Thalassina* specimens exhibit a striking uniformity in their appearance and presentation. They occur in concretionary nodules of calcareous mudstone, being weathered to various degrees, that may obscure all but a few portions of the most prominently projecting structures of the carapace. Conversely, specimens may weather to the extent that the more durable carapace material, except for its subtending and interstitial matrix, becomes almost entirely exposed.

Concretions containing mudlobster fossils are easy to recognize on the basis of their size and length to diameter proportions, but most specimens occur in a partially weathered condition in which the abdominal segments and the tips of the chelipeds are exposed. The exoskeleton invariably occurs with its chelipeds extended horizontally in front of the carapace, the latter being represented by paired side plates (the branchiostegites) that are deflected away from the midline of the thorax resulting in a greatly expanded basin or trough in which the slumped anterior carapace, or "head end" of the animal can usually be found. The abdominal segments commence immediately posterior to the

gaped branchiostegites where in dorsal aspect, two or three of the anterior most tergites are often visible. The remaining portion of the abdomen, viewed in ventral aspect, is flexed tightly beneath the thoracic region where the distal end of the telson comes to lie as far forward as the third leg base. Amateur collectors commonly confuse the dorsal for the ventral side of the animal which gives the impression of a long, segmented abdomen curling tightly over a broad, compressed "back". This, in conjunction with the fully extended chelipeds has resulted in the widespread misconception that the mudlobster fossils are "scorpions".

The hardness, texture and colour of the matrix and colour and hardness of the preserved exoskeleton of fossil *Thalassina* differs from one locality to the next. Specimens from the Daly River estuary are typically light bluish grey in a light tan matrix with a chalky texture which is easily scraped away by the thumbnail. *Thalassina* fossils from the mouth of the South Alligator River are greyish white, embedded in a homogeneous tan-grey matrix which also readily scrapes away on the surface, but grades into a harder, dark grey material a few millimetres deep from the surface. The concretions from

South Alligator River are often large and somewhat irregular in shape. Fossil *Thalassina* collected by Russell Hanley from the King River, Kimberleys, Western Australia, while typical in all basic characteristics, but having thin, patchy representation of the exoskeleton are the least well preserved. Four of the five specimens in our collection consist entirely of internal casts of light grey mudstone. Specimens collected from Ludmilla swamp, a mangal located about 5 km from the N.T. Museum, have well preserved exoskeletal elements of a yellowish-tan colour embedded in an organically rich compound of shelly, bioturbated mudstone with iron oxide flecks.

The most attractive and sought after specimens from the Darwin area are collected at low tide from a sandy beach located near Gunn Point, several kilometres north of a minor estuary called Hope Inlet. These have very hard, rich reddish-brown to black exoskeletons embedded in a fine, homogeneous reddish brown to light reddish tan coloured matrix that resists scratching by the thumbnail. Because the matrix is very hard and the exoskeleton is darkly stained and evenly polished by having rolled around in the sandy littoral zone of the beach, they give an impression of greater antiquity than the

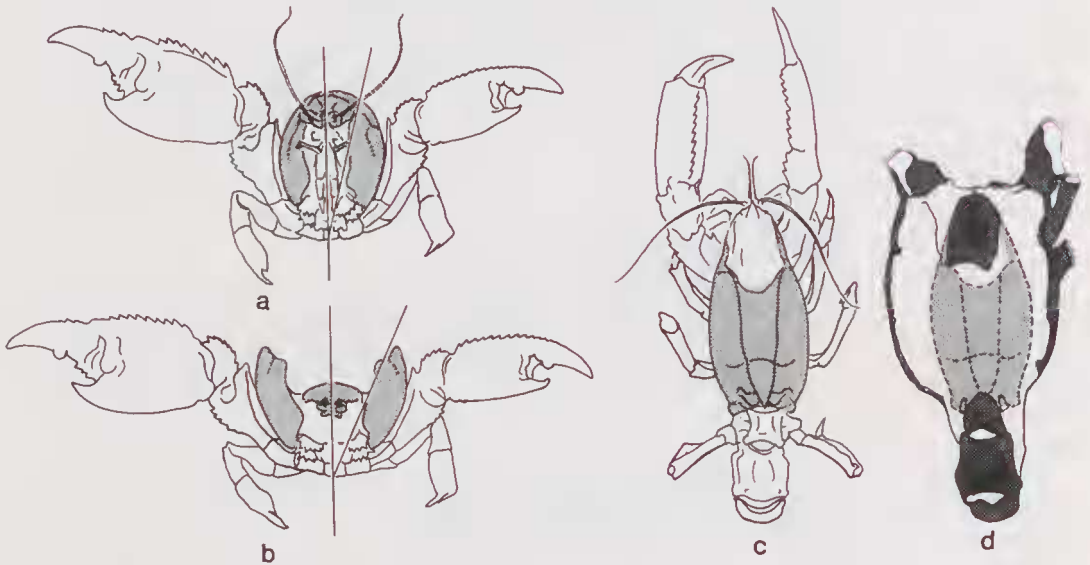


Fig. 4. Relative positions of carapace sections before and after moult: **a**, stippled area shows shape of carapace in a live specimen; **b**, the branchiostegites have been displaced laterally and the dorsal sections of the carapace sink into the body cavity; **c**, dorsal view of intact carapace in a live specimen; **d**, during the moult, the branchiostegites are displaced laterally and the head cap is tilted forward. The posterior section of the carapace cannot be seen in the fossil specimen shown.

rest. The matrix of specimens from all localities show a strong reaction to acid but vary somewhat in amount of incorporated organic debris and metallic oxide staining. These differences relate to the nature of the substrate in which the fossils formed, the proximity of iron and manganese oxide deposits (principally laterites) and certain post-depositional processes that have affected fossil assemblages after removal from their beds of origin. More will be said about this under fossilization processes and dating.

Thalassina fossils are by far the most common species in these assemblages. At Gunn Point, *Thalassina* concretions comprise about one third of the total identifiable material consisting primarily of fossilized wood fragments, teredo worm tubes, mud whelk shells and mud crab chelipeds (rarely the carapace). Segments of burrow casts, some undoubtedly representing *Thalassina* burrows, others possibly representing various burrowing crustacea and polychaete worms are also common. The great abundance of fossil *Thalassina* remains has resulted in much verbal speculation as to the circumstances of their origin. Most of these ideas involve some notion of mass mortality or a specific, temporally defined geomorphological event that might facilitate the preservation of such material. Hyposalinization of an estuary due to flooding with fresh water, possibly during a cyclone; hypersalinization of the habitat due to stream course changes, estuarine remodelling or drought; local uplift; sea level depression and increased sediment loads resulting in a rapid infiltration of *Thalassina* burrows with silt have been suggested as causal factors. As will be demonstrated, an explanation of the abundance of *Thalassina* fossils requires none of these elaborate hypotheses, because they represent moulted exoskeletons, a considerable number of which are shed by each individual during its normal life cycle.

EVIDENCE THAT THALASSINA FOSSILS REPRESENT MOULTS

Thalassina fossils occur in a characteristic posture consisting of a horizontal extension of the chelipeds, inferior and backward displacement of the anterior carapace ("head"), the branchiostegites (side walls of the thorax) are displaced laterally and the tail (abdominal segment) is curled tightly beneath and is

closely approximated to the inferior thorax. On some specimens, the dorsal midline plate which in the living animal forms the back of the carapace, has come to lie in front of the anterior carapace. This posture, known as "Salters position" is commonly seen in ecdysized (moulted) crustacean exoskeletons. Among the hundreds of specimens from the Darwin area examined by us, any exception to this characteristic position would be regarded as highly unusual.

In dorsal aspect, the fossil mudlobsters are 1.5 to 2.0 times as wide across the carapace than living or preserved specimens of equal length. The reason for this is readily observed in frontal view. The anterior margins of the branchiostegites are nearly vertical relative to the midline in living specimens whereas the fossils describe a much greater angle (Fig. 4), suggesting that they have been pushed outwards. This "exploded" condition contributes to the superficially scorpion-like appearance of the fossil specimens, as does the fully-extended position of the chelipeds. The anterior carapace, having collapsed inferiorly and the absence of the posterior carapace (both are usually partially or wholly obscured by the matrix that has infiltrated the interior of the thorax) create the impression of a low profile arthropod, whereas the intact *Thalassina* has a very deep carapace with a convex profile.

The lateral displacement of the branchiostegites, the displacement anteriorly or laterally of the dorsal, posterior carapace, the consistent, posteriorly retracted and inferior displacement of the "head" (anterior carapace), and tightly adducted abdominal segments (Fig. 5) provide the strongest evidence for the mudlobster fossils representing preserved successive, moulted exoskeletons of *Thalassina*. This fact also accounts in part for the local abundance of the fossils which seems out of proportion to the other fossil mangrove species that occur in association with them. The other factor of singular importance is that the mudlobsters undergo ecdysis in their burrows, in conditions more conducive to preservation than surface-moulting crustaceans. It is therefore unnecessary to postulate instances of mass mortality due to freshwater flooding (to which *Thalassina* is very resistant) or prolonged periods of drying of the substrate due to uplift, estuarine channel shifts or other

geomorphological phenomena to account for the abundance of mudlobster fossils.

The condition of fossil *Thalassina* permits the reconstruction of the general pattern of exoskeletal exuviation, which to our knowledge, has not been recorded from a living specimen.

MODE OF ECDYSIS INFERRED FROM FOSSIL THALASSINA

In common with all Anomura, *Thalassina* emerges from the dorsal midline of its moulted carapace through a trap-door mechanism in the posterior cephalothorax. (see Fig. 6). The adaptation is well suited to moulting in confined spaces because the posterior and arching component of withdrawal from the old carapace is minimized. The gastric and cardiac segments of the postero-dorsal cephalothorax are separated from the branchiostegites by a clearly defined pair of grooves, the *lineae thalassinica*. Hormonal changes that initiate the molt reduce the integrity of the seams that finally give way to muscular pressure resulting in the separation of a long tapering flap of exoskeleton. As the animal arches and withdraws posteriorly, the gastric flap is forced upwards, remaining connected by thin membranes on either side of the posterolateral margins of the cervical groove. As the "head" is withdrawn from the anterior carapace, which has simultaneously separated from the branchiostegites in the area of the hepatic groove, the anterior carapace is dragged posteriorly and eventually collapses to lie well inferior to its original position. Having freed its anterior end, the mudlobster commences withdrawing its chelipeds and anterior appendages while moving its whole body anteriorly. The forward movement often pushes the gastric plate over the anterior carapace so that it may come to lie anterior to it, although in an equal number of fossils, the gastric plate is pushed sideways where it comes to lie alongside the anterior carapace. The action of withdrawing the chelipeds results in the extension of the cheliped exuviae into a horizontal plane parallel with the body. A specialized anterior abdominal tergum (the first dorsal plate on the abdomen) rotates backwards to facilitate the withdrawal of the abdomen. The muscular action of the abdominal withdrawal process results in characteristic tightening of the curl of its tail,

the last segment of which comes to lie much further anteriorly beneath its body than in its usual living posture. The newly moulted *Thalassina*, freed from its old carapace, probably remains in the moulting chamber at least long enough to harden its carapace for renewed digging activity. This may result in secondary, though slight, disturbance of the classic Salter's position of the moulted carapace. It may also initiate the fossilization process of the moult by backfilling the evacuated chamber with finely turbated material that may have accumulated during the resting period.

TAPHONOMY AND DATING OF THALASSINA FOSSILS

All of the known sources of *Thalassina* fossils in northern Australia occur in or in close proximity to present day mangrove littoral deposits where living *Thalassina* are known to occur. Comparison of living and fossil *Thalassina* specimens from the same general area indicate they are probably the same species. Synonymy has not yet been verified by systematists because the diagnostic features revealed by the antennule and antenna bases are either obscured by matrix or eroded away. We consider the local living species to be *T. anomala* and the local fossil species to be *T. cf. anomala*. Some fossil *Thalassina* localities contain *in situ* fossils. These beds are exposed during low tides. The fossils can be seen protruding slightly above the surface of mud bars in the mouth of the Daly River. At Kapalga Landing, South Alligator River, the concretionary nodules containing *Thalassina* occur scattered on the muddy surface exposed at low tide. However, the Shoal Bay specimens collected from the sandy beach South of Gunn Point are found several kilometres from the estuary (Hope Inlet) where a vast area of suitable habitat for the species *T. anomala* is located. Surveys of the Shoal Bay beach have revealed no likely source for them in the immediate area of their greatest abundance. The only consolidated sedimentary rocks exposed above the high water mark are beach rock and recent calcarenites that are lithologically incompatible with the fossils. The Cretaceous rocks exposed at very low water in the area are also lithologically incompatible with the mud lobster fossil matrix. Shoal Bay *Thalassina* fossils were occa-

sionally reported to have come from visible outcrops but none of these could be verified. Concretions are secondarily deposited in crevices in the beach rock and calcarenites by wave action, along with other strand debris; providing a likely explanation for the observations. The Shoal Bay locality can therefore be narrowed down to two possible sources for the fossils: they originate from the tidal estuary of Hope inlet and are carried by strong currents to the approximate central portion of the beach or they are eroded from sediments below the low water mark to seaward of the area of their greatest abundance. Either way, their original source is equally distant as exploration of the beach on the lowest spring tides indicates the sand deposit extends at least several kilometres into Shoal Bay waters. The latter hypothesis infers a major change in the Hope Inlet-Shoal Bay shore line geomorphology, whereas the Hope Inlet source does not require elaboration.

Recently excavated drains cut through the Ludmilla mangal provided a unique opportunity to examine extensive sections through a typical muddy littoral deposit in which mudlobsters occur. We found not only the extensive burrow net-works of living mudlobsters, but *in situ* fossil *Thalassina*. Examination of the sediments in the bottom of ditches and in section along the sides gave a strong indication that hard, concretionary fossils and burrow casts *in situ* could not be distinguished stratigraphically from active burrow systems, and in many instances proved to be interconnected. Moreover, in the organic-rich, high littoral areas where the cuttings were made, the concretions encasing mud lobster fossils contained organic debris in the same, apparently very recently incorporated, state of preservation as in the surrounding, presently actively bioturbated substrate. From a geological point of view, the Ludmilla mudlobster fossils are essentially modern. The Ludmilla substrate is much coarser than the substrates represented in lower littoral fossil mudlobster sources that are only exposed at low water. This is due to a higher detrital content and more prolonged periods of exposure to the air and higher ambient temperatures at the surface which seem to encourage the formation of concretionary nodules. The high density of concretions, consisting primarily of *Thalassina*

burrow casts, made excavation by shovelling extremely difficult. It is of course, possible that the occurrence of *in situ* fossil mudlobsters and their burrows along with living, actively burrowing mudlobsters is due to a previous lowering of the sea level with resultant fossilization, followed by a re-invasion of the area by mudlobsters after the sea level returned to its present level. However, the uniformity in the conditions of organic material in the fossil concretions and adjacent active burrows, and the lack of any distinctive bands of previous laterite development seem to support the probability of an ongoing, continuous process of fossilization of mudlobsters at Ludmilla swamp throughout later Holocene times to the present. The Ludmilla swamp example indicates that the majority, if not all of the mudlobster fossils are of very recent origin, probably mid-Holocene and less in age (5000 B.P.) and accounts for the lack of clearly defined stratigraphic delineations for beds containing the concretions. Their abundance and widespread distribution is also explained by the fact that they represent successive moults of numerous individuals. The fossilization process is continuous, rapid and occurs in virtually every major estuary in northern Australia. The rate of the fossilization process is indicated by the rapidity at which mangrove mud, taken from mudlobster burrows attains a concrete-like hardness. Mud samples removed from Ludmilla were gently compacted in balls of approximately 10 x 15 cm and sealed in plastic bags. These hardened to a thumbnail scratch consistency within a month, although they are less hard and have less mass by volume than the naturally occurring concretions. Iron oxide stains and incipient mineralization of the mudballs had also commenced. The natural casts and concretions differ in having formed around a nucleus of carbonate-rich material, either shells or mudlobster exoskeletons. They have also undergone *in situ* lateritization in which metallic oxides have been mobilized by the tidal fluctuations of the water table. While there is no experimental evidence other than the "mudballs" to support our observations, it seems very probable that very hard, dense concretions can develop in a matter of a few years of mineralogical transfer, recrystallization and oxidation in a carbonate rich environment with a rapidly fluctuating

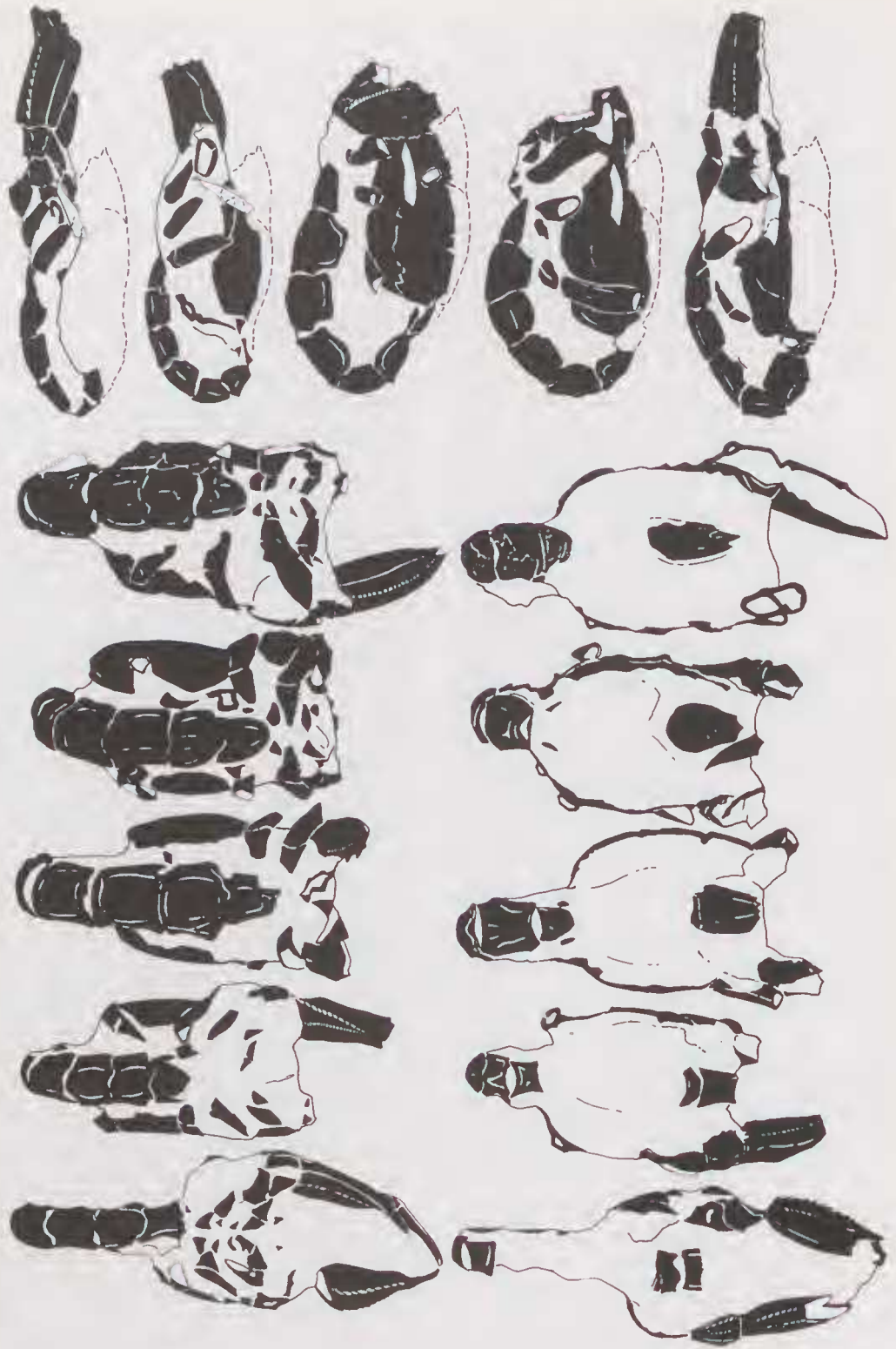


Fig. 5. A range of *Thalassinia* fossils showing little variation in the relative positions of body parts. The similarity of all fossil mudlobsters configurations demonstrates the moulting process is the likely cause.

tuating water table and high water temperatures.

The Shoal Bay mudlobster fossil mode of occurrence and appearance can be explained as being the result of circumstances of fossilization similar to that of Ludmilla swamp. The source of the fossils however, is from a finer sedimentological regime nearer the low water mark than those of Ludmilla swamp. Mudlobsters moult within a chamber developed as a *cul de sac* in their burrow network. The exuviated exoskeleton forms a nucleus for the development of a concretion from the backfill of the chamber abandoned by the emergent *Thalassina*. The concretions are eventually brought to the surface of the substrate by normal bioturbation and local changes in erosional foci after which they are tumbled along an expanse of several kilometres of sea bed by strong tidal currents and washed ashore by wave action. All of the specimens from Shoal Bay beach are extensively rolled, indicating a relatively long distance of transport from their original source. If the source were immediate to their area of occurrence we would expect to find some unweathered examples, ie. if washed straight in from a subtidal source directly out from their stranded position. The difference in colouration and greater hardness of the Shoal Bay or Gunn Point mudlobster fossils is due to a process of secondary permineralization due to contact with the iron- manganese rich sediments of the local Shoal Bay sea bed that, as it is carried in solution, is attracted to the carbonate-laden concretionary material and exoskeleton. The differential colouration of the shell and matrix is directly related to the proportion of carbonates to other minerals present, resulting in a higher infiltration of oxides in the predominately carbonate exoskeleton. The iron-manganese source in the Shoal Bay area is eroded laterite material which comprises a significant fraction of the beach sand.

EVIDENCE FROM MANGROVE SWAMP DATING AND GEOMORPHOLOGY

Recent studies of mangrove swamp development in the Northern Territory

coastline (Woodroffe, Thom and Chappell 1985) indicate that the formation developed from 6,500 to 7000 radiocarbon years ago, coincident with the last stage of the post glacial sea level rise. Subsequent to its initial, very extensive spread, as determined by core drilling, the mangrove swamps underwent a dramatic reduction in extent by about 5,500 years ago in response to continued sedimentation resulting in black soil plains. The present extent and pattern of mangrove facies was established in mid-Holocene times indicating that the mud-lobster fossils can be no older than about 7000 radiocarbon years if recovered *in situ* from the oldest mangrove facies, but are more likely to be younger than 5,500 years old if they are recovered from derivative deposits such as Shoal Bay beach (Gunn Point). It is unlikely the phase of mangrove swamp reduction that occurred between 7000 and 6500 years ago was solely responsible for the mudlobster fossil deposits because subsequent extensive down cutting and substantial stream channel changes would be necessary to expose the previously choked out beds. However even if the fossils could be attributed primarily to a single event of approximately 1000 years duration, their recent origin is well established.

We conclude that the mudlobster fossils are all post-Pleistocene age, no older than 7000 radio carbon years, and probably considerably younger. Because they invariably represent moulted exoskeletons, the evidence for an event based mass mortality of *Thalassina* due to increased sedimentation seems unlikely. The evidence from Ludmilla Swamp supports the proposition that the formation of *Thalassina* fossils is a continuing process, but the rate at which the concretions develop has not yet been established.

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Fig. 6. Stages in the moult of *Thalassina anomala*; a, rupture of cephalothorax along lineac thalassinica; b, posterior dorsal section of cephalothorax pivots around hepatic groove and is rotated forward and laterally by bulging out of animal's anterior end; c, cephalothorax is free as is major cheliped, animal struggles to free rest of legs; d, using legs braced against old exoskeleton animal extracts abdominal segments.

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